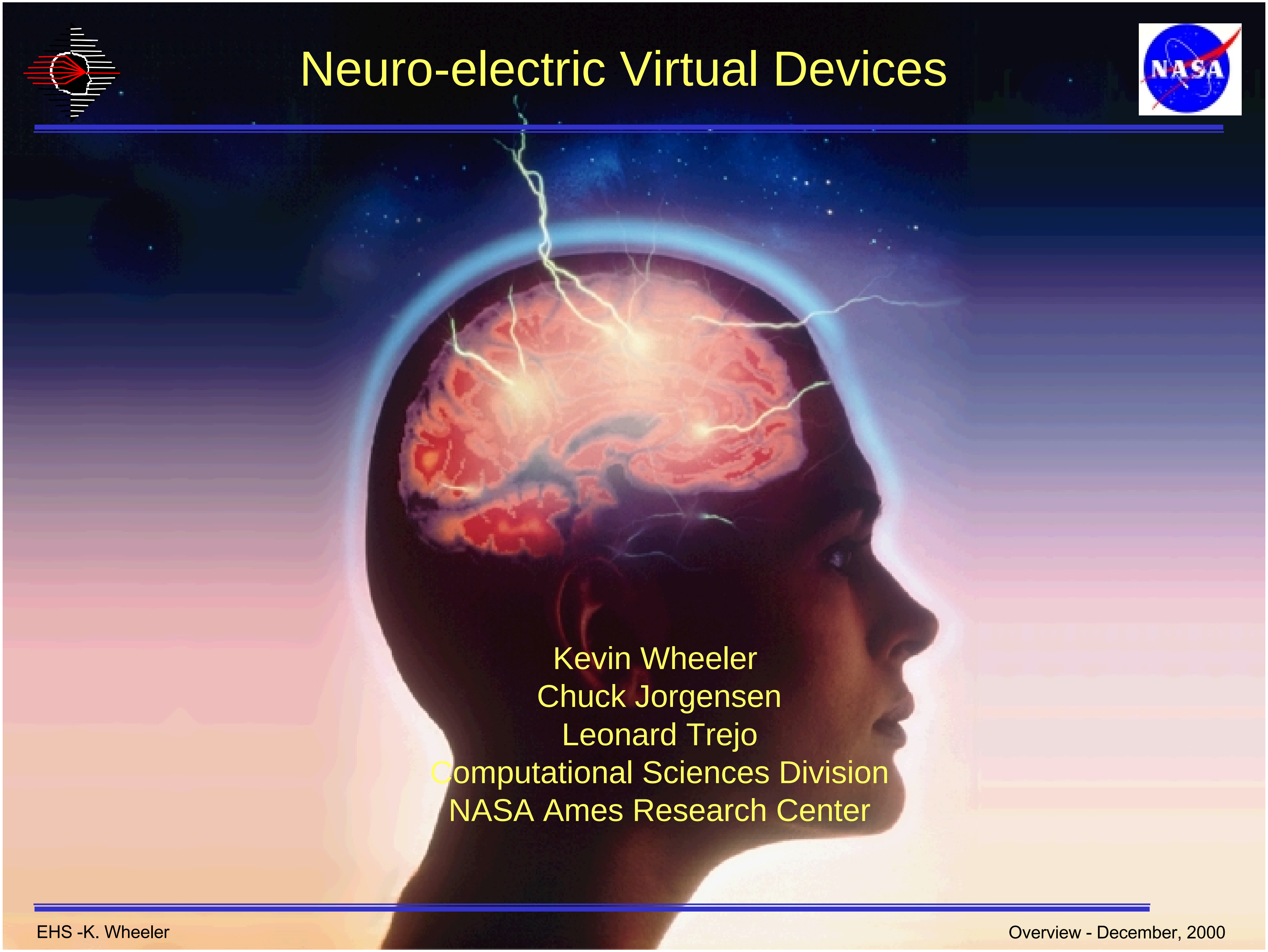
Neuro-electric Virtual Devices



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Overview

- Extension of Human Senses Program
- EMG Signal Acquisition & Experiment Design
- EMG Signal Processing & Recognition Approach
- Wearable EMG Hardware
- Bioelectric Joystick and Keyboard Film

Extension of Human Senses
Trends in Personal Computing

Laptops and PDAs have been evolving as follows:

Larger screens - size limited by carrying convenience, can be replaced by active display glasses.

Smaller, faster motherboards - wearable cases

Spoken command input - speech recognition works for common words but not good for programming and science tasks

Full size keyboards - Design has NOT evolved. The physical size of input keys limits the evolution of cell phones, laptops, command panels, aircraft instrumentation …

Extension of Human Senses
Bioelectric Keyboard NASA Applications

Wearable Cockpit - virtual instrumentation, moves with pilot, works for AUVs and manned missions. Provides for faster and cheaper reconfiguration, and safety monitoring of pilots.

Spacesuit restricted typing - allows for typed data entry while wearing spacesuit or within confined environments.

Natural robotic arm interface - joystick can be replaced with a more natural interface.

Exoskeleton EMG interface - provides capability of working in extreme environments and manuvering heavy items. Provides for training exoskeleton to do tasks autonomously.

Extension of Human Senses
Electrode Types & Locations

Electrode Types:

- *Wet temporary* - Ag/Ag Cl stick on temporary electrodes
- *Wet gel/metal cups* - attached with super glue
- *Dry* - metallic composition affixed by elastic

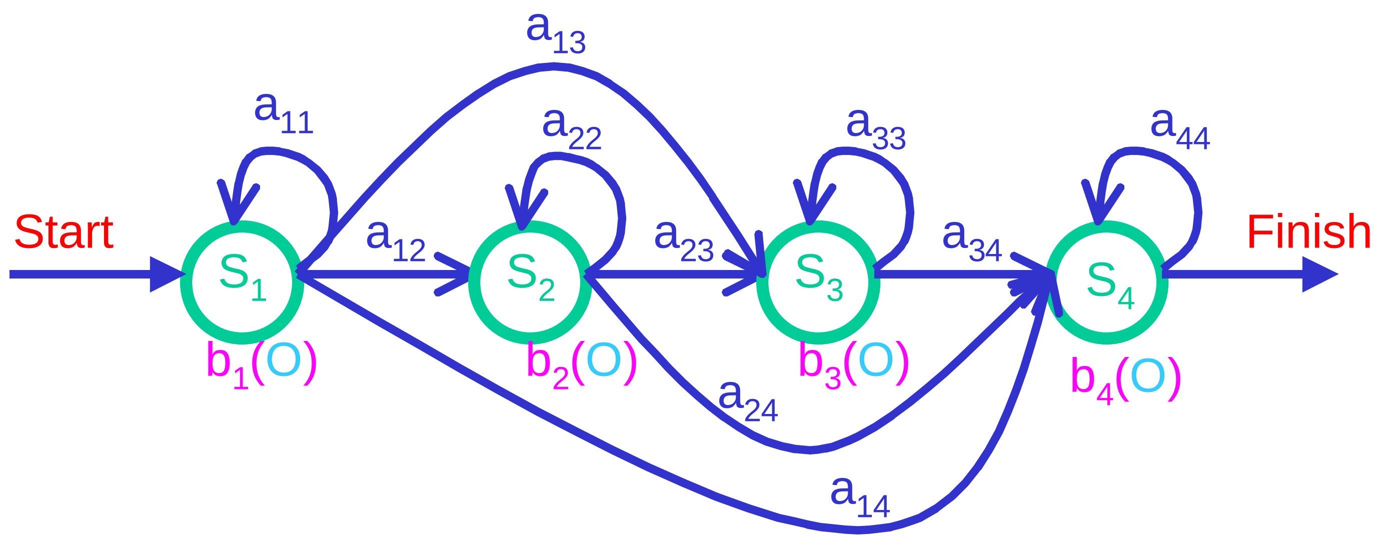
Electrode Positions:

- *Broad gestures* - large muscle groups, similar across people
- *Finer gestures* - proper position requires spatial over-sampling with reduction.

Example Placement:

- *Joystick* - four electrode pairs on forearm
- *Typing* - eight electrode pairs on forearm

Extension of Human Senses
Hidden Markov Models



a_{ij} $P(q_{t+1}=S_j|q_t=S_i)$ transition probability from state i to state j

$b_j(O) = P(O|q_t=S_j)$ probability of observation when in state j at time t

S_j State j,

π_j probability of state j

$$b_j(O) = \sum_{m=1}^{M} c_{jm} \mathcal{N} [O, \mu_{jm}, \Sigma_{jm}] ,$$ mixture model

Extension of Human Senses
Hidden Markov Model Overview

Initialization - The initial state probability densities are formed with variance based state partitioning with per state clustering.

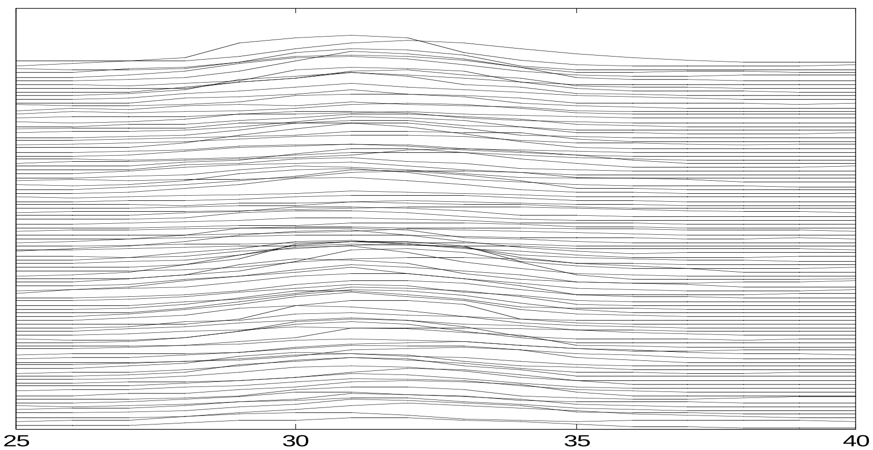
Features - Overlapping moving averages of the absolute values of the signals.

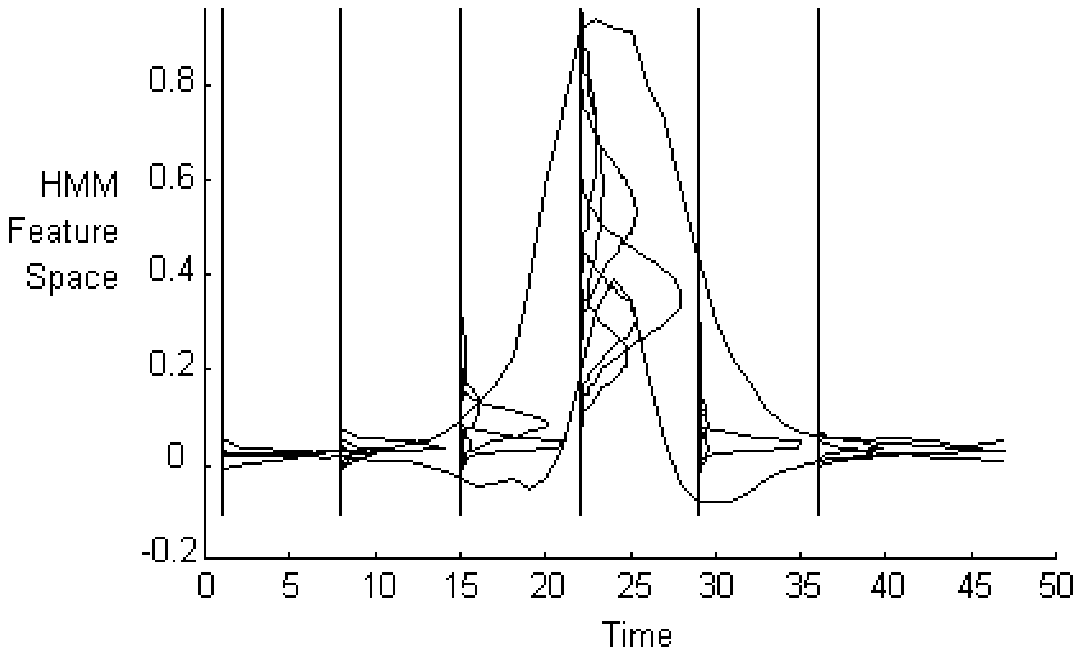
Training - Standard Baum-Welch training is employed.

Recall - Viterbi based recall is used.

Real-time Recall - Uses multiple identical recognitions in a row.

Extension of Human Senses
HMM Initialization





Extension of Human Senses
Inference Models

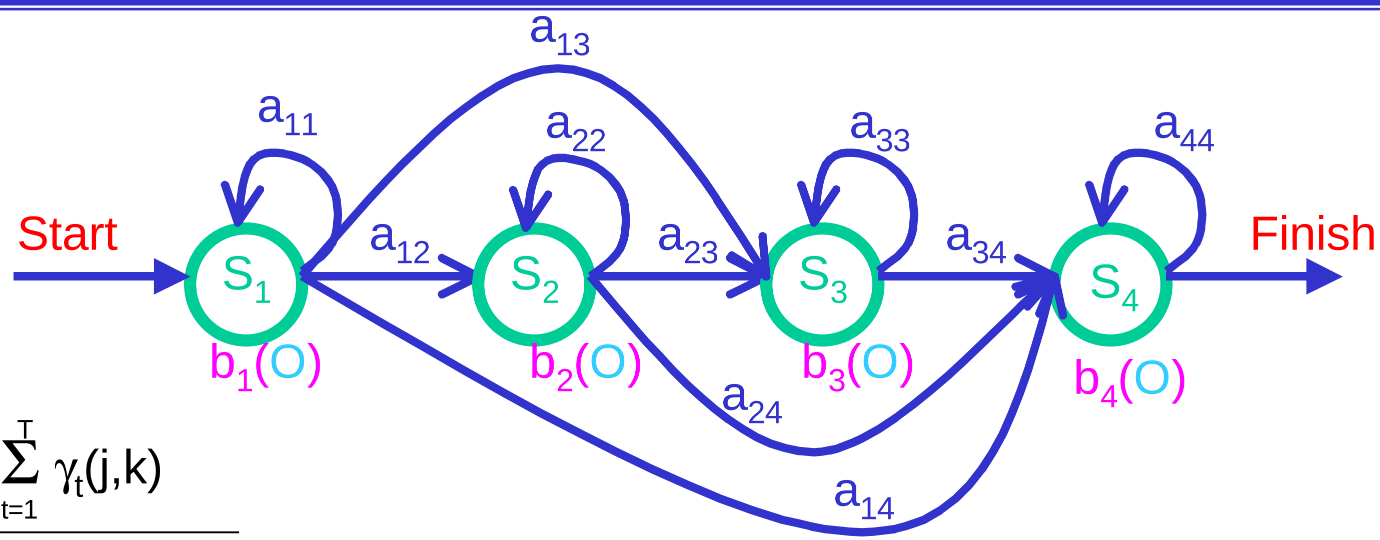
Real World Problem Domain:

- Non-stationary time-series
- Non-Gaussian distributions of feature values
- Dependence between features and channels
- Real-time recall requirement
- On-line adaptation capability
- Multi-user context switching

Quick & Dirty Tradeoffs:

- Short time windows and transforms
- Mixtures, Gram-Charlier, Multi-scale
- Eliminate via mutual information
- Exp() macros, focused computations
- Vary as little as possible
- Simple voting schemes

Extension of Human Senses
HMM Training



$$c_{jk} = \frac{\sum_{t=1}^{T} \gamma_t(j,k)}{\sum_{t=1}^{T} \sum_{m=1}^{M} \gamma_t(j,m)}$$

$$\gamma_t(j,k) = \frac{\alpha_t(j)\ \beta_t(j)}{\sum_{j=1}^{N} \alpha_t(j)\ \beta_t(j)} \ \frac{c_{jk} N(\mathbf{O}_t,\ \mu_{jk},\ \Sigma_{jk})}{\sum_{m=1}^{M} c_{jk} N(\mathbf{O}_t,\ \mu_{jk},\ \Sigma_{jk})}$$

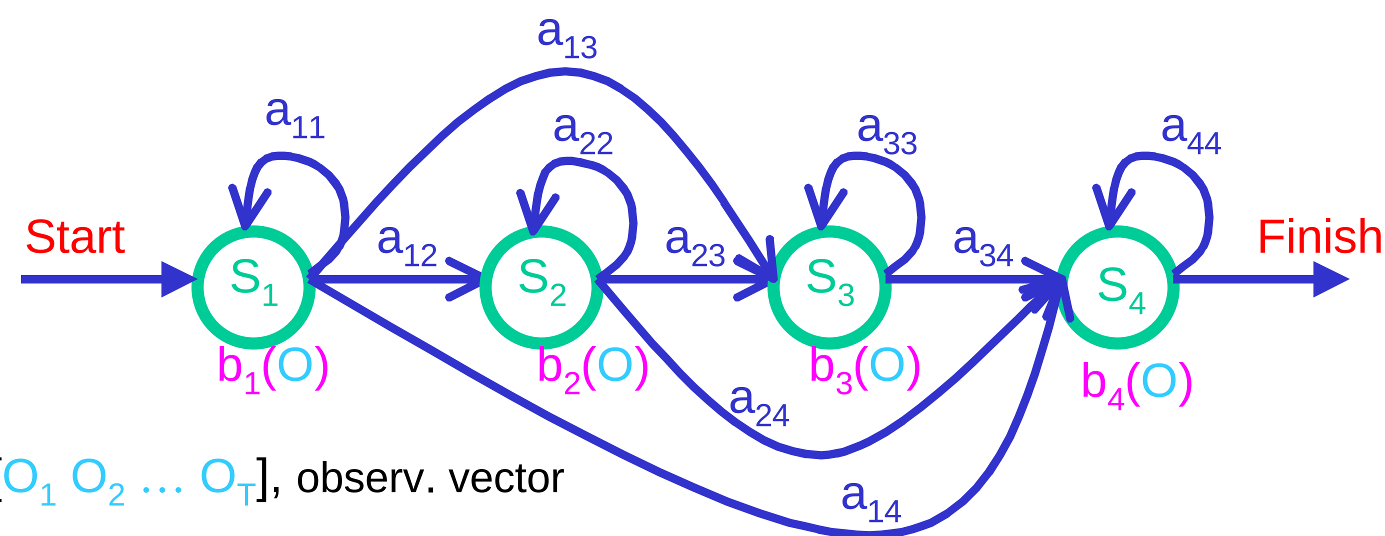
$$\mu_{jk} = \frac{\Sigma \gamma_t(j,k) * \mathbf{O}_t}{\Sigma \gamma_t(j,k)}$$

$$\xi_t(i,j) = \frac{\alpha_t(i) a_{ij} b_j(O_{t+1}) \beta_{t+1}(j)}{P(O|\lambda)}$$

$$\Sigma_{jk} = \frac{\sum_{t=1}^{T} \gamma_t(j,k) * (\mathbf{O}_t - \mu_{jk})(\mathbf{O}_t - \mu_{jk})^T}{\sum_{t=1}^{T} \gamma_t(j,k)}$$

$$a_{ij} = \frac{\sum_{t=1}^{T} \xi_t(i,j)}{\sum_{j=1}^{N} \sum_{t=1}^{T-1} \xi_t(i,j)}$$

Extension of Human Senses
Viterbi Recall



$O = [O_1\ O_2\ \ldots\ O_T]$, observ. vector

$Q = [q_1\ q_2\ \ldots\ q_T]$, state seq. vector

$$P(Q|\lambda) = \pi_{q1} a_{q_1 q2} a_{q2q3} \ldots a_{qT\text{-}1qT}$$

$$P(O|Q,\lambda) = b_{q1}(O_1)\ b_{q2}(O_2)\ \ldots b_{qT}(O_T)$$

$$P(O|\lambda) = \sum_{\text{all } Q} P(O|Q,\lambda)\ P(Q|\lambda)$$

$$P(O|\lambda) = \sum_{q_1, q_2, \ldots, q_T} \pi_{q1}\ b_{q1}(O_1) a_{q1q2} b_{q2}(O_2) \ldots a_{qT\text{-}1qT} b_{qT}(O_T)$$

i) $\alpha_1(i) = \pi_i b_i(O_1) \quad 1 <= i <= N$

ii) $\alpha_{t+1}(j) = [\sum \alpha_t(i) a_{ij}] b_j(O_{t+1}) \quad 1<=t<=T\text{-}1$

iii) $P(O|\lambda) = \sum \alpha_T(i)$

Extension of Human Senses
Visualization & Understanding

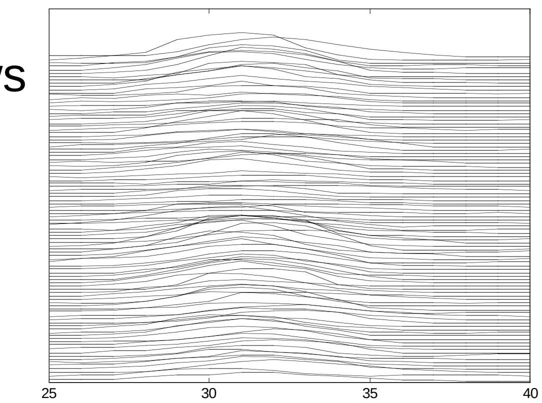
Areas of Understanding

Error Analysis

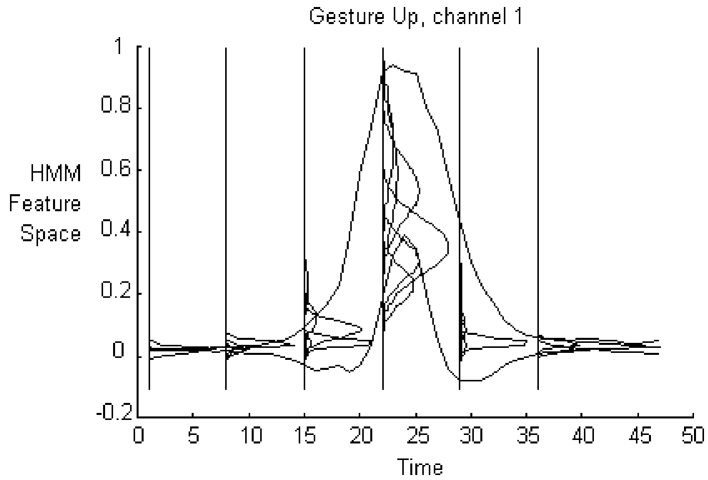
- ROC curves
- Confusion Matrix
- Error vs. parameters

Data Domain

Alternative views such as this multi-day plot.



Models



English Explanations

Automated transformation from model space to words:
Typing one is best separated from typing five by channel 6 time slice 4.

Extension of Human Senses
Typing Demonstration

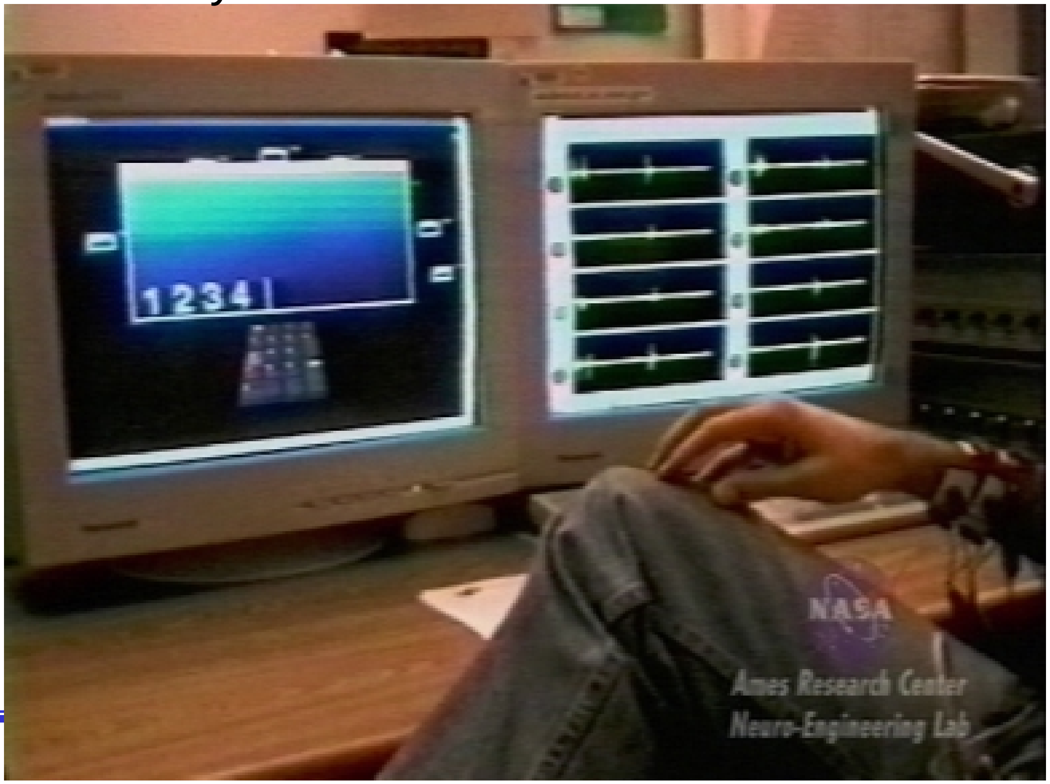
Demonstration: Eight channels of EMG are recognized as keystrokes when pretending to type on a keyboard number pad.

Purpose:

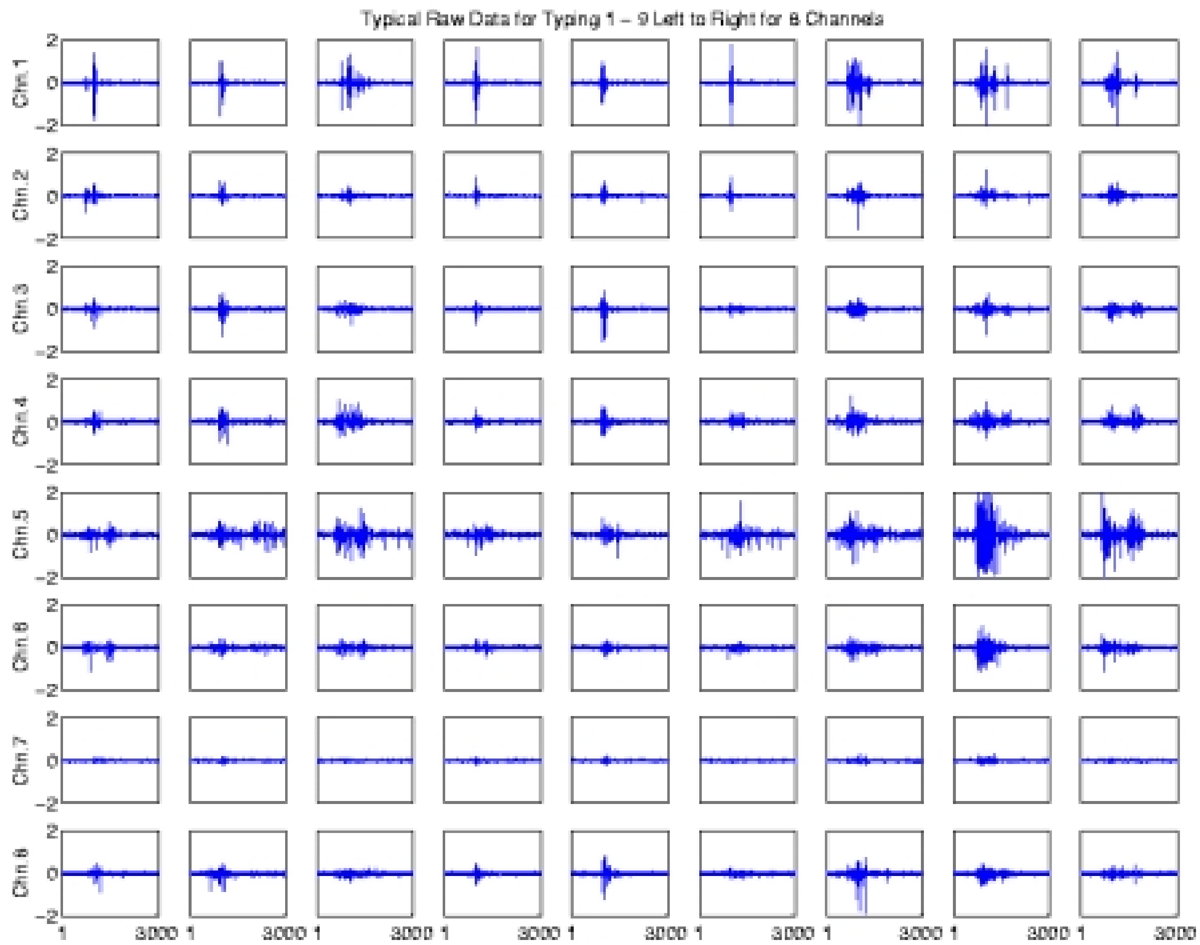
- qwerty keyboard is not the ultimate interface but it is most familiar
- alternative typing methods require additional user training
- hands are free of gloves and other apparatus
- typing capability leads to other more friendly interfaces

Issues:

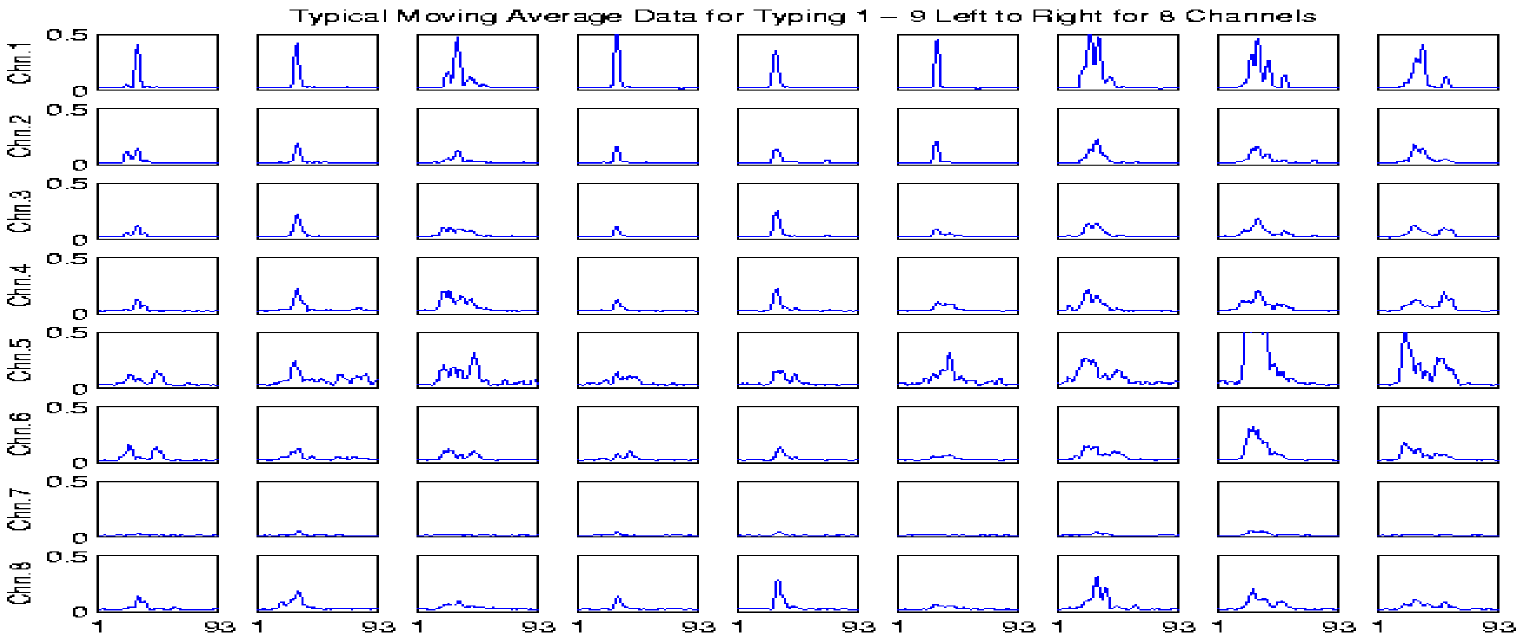
- Typing style is critical
- Finer gestures need adjustment to individual
- Small sensor development



Extension of Human Senses
Typing Data



Extension of Human Senses
Typing Data



Extension of Human Senses
Mutual Information Analysis

Mutual information measures how independent two random events are by using the information contained in their probability distributions.

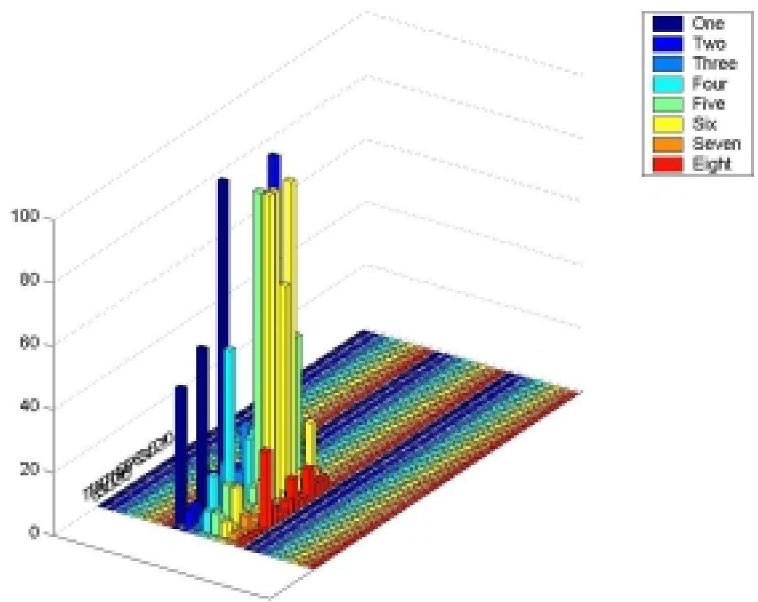
In the numeric pad typing example, the independence of the time-sliced data can be measured in a number of different ways:

Single Time Single Channel (STSC) - one time-slice and channel for gesture X can be compared with the same time and channel for gesture Y.

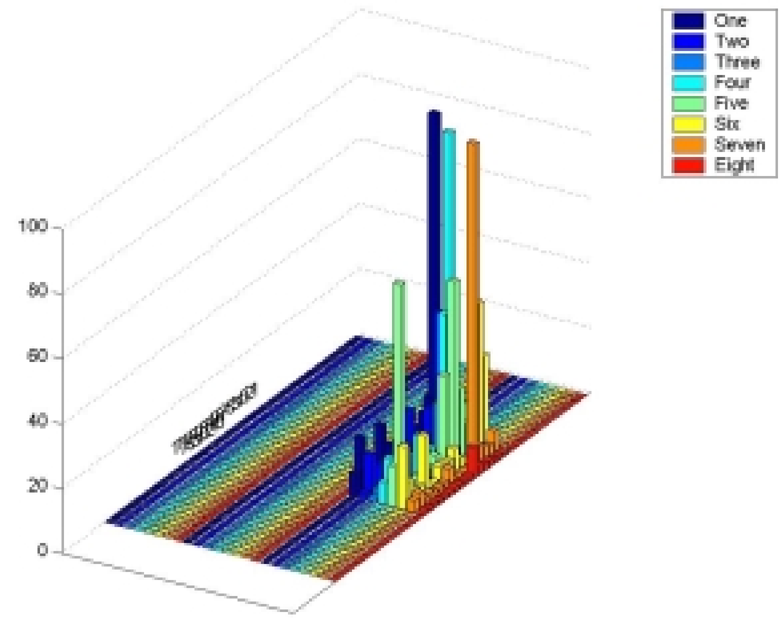
Multi-Time Single Channel (MTSC) - one time-slice and one channel for gesture X can be compared with all time slices and the same channel for gesture Y.

Multi-Time Multi-Channel (MTMC) - one time-slice and one channel for gesture X can be compared with all time slices and all channels for gesture Y.

Extension of Human Senses
Mutual Information (STSC)



Comparing independence for pressing “1” with pressing “3” for each channel across time.



Comparing independence for pressing “4” with pressing “6” for each channel across time.

Note that different channels are important at different times for distinguishing between key presses. For “1” vs. “3” channels 5 and 6 are important, for “4” Vs. “6” channels 4 and 7 are significantly different.